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Technical Report 45

THE PROSPECTS FOR BIOLOGICAL CONTROL OF NONNATIVE PLANTS IN HAWAIIAN NATIONAL PARKS

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ABSTRACT

National Park Service (NPS) policy emphasizes the preservation of processes through which native ecosystems arose, as well as the unique features of such ecosystems. Encroachment of exotic (nonnative) plants into natural NPS areas is inconsistent with this policy. Previous attempts to control such plants in Hawaiian NPS areas have involved mechanical removal or treatment with herbicides, but these methods as presently employed are inadequate to provide control on a long-term basis for many exotic species. They are also expensive and continuous.

Previous efforts to control noxious weeds in Hawaii with phytophagous insects have been conducted by the Hawaii State Department of Agriculture primarily for agricultural interests. Similar approaches for the control of exotic plants in Hawaii Volcanoes and Haleakala National Parks may have positive as well as cautionary aspects which must be considered. A literature review revealed numerous references to insects and diseases associated with Hawaii's exotic plants, or related species, in other regions of the world. Some of these, or other suitable organisms not reported here, may offer potential in future biological control programs.

TABLE OF CONTENTS

ABSTRACT. i

LIST OF TABLES. ii

INTRODUCTION. 1

Statement of the Problem. 1

THE HISTORY OF BIOLOGICAL CONTROL OF WEEDS IN HAWAII. . . . 4

Biocontrol of Lantana in Hawaii--A Case History 7

PREVIOUS EXOTIC PLANT CONTROL EFFORTS IN HAWAIIAN NPS AREAS 10

CONSIDERATIONS FOR BIOCONTROL IN HAWAIIAN NPS AREAS 12

SPECIFIC EXOTIC PLANS FOR WHICH BETTER CONTROL IS DESIRED IN HAWAII VOLCANOES AND HALEAKALA NATIONAL PARKS. 16

RESEARCH AND RESOURCES MANAGEMENT CONCERNS. 31

REFERENCES. 33

LIST OF TABLES

Table

1 The status of biological control of weeds in Hawaii, 1981 49

INTRODUCTION

Statement of the Problem

Weeds, commonly defined as unwanted plants, or plants out of place, are undoubtedly a problem in every country of the world where they occur either as native plants or were accidentally or purposely introduced (e.g., as ornamentals, ground cover, potential agricultural crops, as living fence plants for sheep). With a few exceptions (such as *Leptospermum scoparium* J. R. & G. Forst. and *Acaena sanguisorbae* Vahl of New Zealand and *Opuntia* spp. of Santa Cruz Island, California, which are native "weeds") introduced weeds have received the most attention with extensive documentation in the literature.

The intent of this paper is to discuss the policy of the National Park Service (NPS) regarding nonnative plants in natural areas, and to evaluate the prospects for the control of these species through the use of phytophagous insects or plant diseases. The section discussing possible utilization of biological control agents in future programs is based on an overview of the literature regarding insects and diseases associated with nonnative plants in Hawaii, or with related species in other regions. No claim is intended or implied by the mention of any organism that such an organism would be either desirable or undesirable as a control agent beyond the speculative points offered in the discussion. Often very little, or no information is recorded in the literature with regard to effectiveness of predation, virulence, host range, reproductive potential, dispersal capabilities, geographical range, etc. of these organisms. This report is not intended in any way to constitute an application, or either an official or unofficial attempt to import any organism into Hawaii for control purposes. Such importation involves a separate, carefully reviewed application procedure as is described later in the report.

Although the literature was searched as thoroughly as was practical within the scope of this report, the treatment of the subject of biological control is an ongoing process with new observations and records continually being supplied and discovered. It should therefore not be assumed that all pertinent references have been noted. Inconsistencies or omissions may be readily apparent. This report serves as a basis upon which the subject of biological control in natural areas may be established for further development.

The purpose of the NPS according to the act whereby it was established is stated as follows (118):

> The Service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

Since the presence of nonnative species of plants and animals deviates from this objective, NPS policy states that "Non-native species of plants and animals will be eliminated where it is possible to do so by approved methods which will preserve wilderness qualities" (118). However, an overriding consideration is that the exotic organism will only be controlled if it interferes with native ecological processes. As indicated above, the control method itself must be in keeping with NPS objectives.

The native or nonnative status of plants in island environments, such as in Hawaii, is particularly easily defined due to the isolation of these islands from continental land masses. Those species which arrived and became established through natural means (without the aid of humans) in ancestral forms and which have currently evolved to be distinct from such forms are termed endemic, whereas plants and animals introduced by humans are considered exotic. Indigenous plants are those which arrived in the Hawaiian Islands by natural means from elsewhere, but which have not evolved to become distinct species from those in other locations where these plants are also considered native. Indigenous species are therefore native to Hawaii as well as to other localities.

In Hawaii, a distinction is made between species introduced by prehistoric Polynesian colonizers and those brought by foreign peoples after the year 1778 when the Hawaiian Islands were first visited by English sea captain James Cook. The NPS considers only those species of the latter classification as exotics and therefore subject to control measures. Some such species have aggressively spread into native ecosystems and are competing with native plants, thereby interfering with native ecological processes.

It is important to this discussion that the philosophy of the NPS in defining the desirability or undesirability of particular plant species is clearly outlined. This concept is frequently misunderstood or not fully comprehended by the general public, and has even been interpreted more liberally on occasion by NPS managers themselves. NPS policy provides for the preservation of native habitats and ecological processes, and for the eradication of all plant species whose presence detracts from this objective, notwithstanding the beauty or attractiveness, horticultural interest, economic importance, or any otherwise desirable qualities of these plants. Hence, NPS areas cannot be used as arboreta or protective refuges for even the most endangered species if such species are not native to the park. This policy often does not coincide with agricultural or other economic interests, or those of individual property owners who cultivate or encourage plants for their aesthetic value without regard to the status of their origins.

According to the Federal Noxious Weed Act of 1974, a noxious weed is defined by the U. S. Department of Agriculture as (184):

> ...any living stage (including but not limited to, seeds and reproductive parts) of any parasitic or other plant of a kind, or subdivision of a kind, which is of foreign origin, is new to or not widely prevalent in the United States, and can directly or indirectly injure crops, other useful plants, livestock, or poultry or other interests of agriculture, including irrigation, or navigation or the fish and wildlife resources of the United States or the public health.

The State of Hawaii is pursuing a program for the control of noxious weeds, which it defines as (75):

> ...gorse and any other plant species which is injurious, harmful or deleterious or which may be likely to become so to the agriculture, horticulture, aquaculture, livestock industries of the State, and to forest and recreational areas and conservation districts of the State, as determined by the department from time to time.

In actual practice, the agricultural and related concerns have received by far the greatest attention of the above-listed areas. Thus, particular plant species may be considered noxious by one agency and desirable by another based on the different objectives of the respective agencies.

An example of this conflict in Hawaii is the shrub a'ali'i (_Dodonaea eriocarpa_ Sm.) which occurs as an indigenous plant (and is therefore included in the "native" category by the NPS) and must be preserved under NPS policy, but which is considered a noxious plant by cattle ranchers (111) where it occupies rangelands to the exclusion of more desirable forage species. Furthermore, kikuyugrass (_Pennisetum clandestinum_ Hochst. ex Chiov.) is considered a noxious weed on the U. S. mainland by the U. S. Department of Agriculture (187). Since it is an aggressive exotic species in Hawaii, it is also an undesirable species in Hawaiian NPS areas, but it is valued as a forage crop by livestock producers in other areas of Hawaii (194, 195). On the other hand, in some instances there is agreement among all concerned agencies as to the undesirability of particular species, albeit perhaps for different reasons (e.g. banana poka (_Passiflora mollissima_ (HBK.) Bailey)).

THE HISTORY OF BIOLOGICAL CONTROL OF WEEDS IN HAWAII

Ranchers, farmers, and government land managers in Hawaii face, and have faced, the constant menace of noxious plants appearing in their domain. Some of these pests, such as prickly pear cactus (*Opuntia* spp.), firebush (*Myrica faya* Ait.), Hamakua pamakani (*Ageratina riparia* K. & R. (=*Eupatorium riparium* Regel)), lantana (*Lantana camara* L.), and Maui pamakani (*A.* (=*Eupatorium*) *adenophora* Spreng.) have in the past rendered thousands of acres useless as pastures. A large expenditure of time and money was necessary to reclaim such lands. In one instance, a newly discovered infestation of piri piri (*Acaena sanguisorbae*), a very serious pest in New Zealand (82), was found on the Waimea-Keanakolu road, Hawaii, and was successfully eradicated by Parker Ranch personnel before it could spread (82).

In state and federal lands, banana poka, common guava (*Psidium guajava* L.), strawberry guava (*P. cattleianum* Sabine), firebush, Hamakua pamakani, Koster's curse (*Clidemia hirta* (L.) D. Don), wild blackberry (*Rubus penetrans* Bailey), yellow Himalayan raspberry (*R. ellipticus* Sm.), fountaingrass (*Pennisetum setaceum* (Forsk.) Chiov.), and broomsedge (*Andropogon virginicus* L.) are some of the important noxious weed pests which have altered the native ecosystems. The biological control program against lantana, which is perhaps the most widely known, has resulted in partial to substantial control of lantana in its wide ecological distribution. This program is discussed in detail as a separate case history due to its importance and thorough documentation.

Following the efforts against lantana, 17 noxious weeds were targeted by the State for biological control. In chronological order these were as follows:

1. Nut grass (*Cyperus rotundus* L.) 1925

2. Maui pamakani (*Ageratina adenophora* Spreng.) 1945

3. Prickly pear cactus (*Opuntia* spp.) 1949

4. Gorse (*Ulex europaeus* L.) 1952

5. Koster's curse (*Clidemia hirta* (L.) D. Don) 1953

6. Brazilian pepper tree or Brazilian holly (locally known as wilelaiki or Christmas berry) (*Schinus terebinthifolius* Raddi) 1954

7. Firebush (*Myrica faya* Ait.) 1956

8. Emex (*Emex spinosa* Campd.) 1957

9. Emex (*Emex australis* Steinh.) 1957

10. Malabar melastome or Indian rhodondendron (Melastoma malabathricum L.) 1958

11. Hairy fleabane or sourbush (Pluchea odorata (L.) Cass. 1958

12. Elephant's foot (Elephantopus mollis H. B. K.) 1961

13. Puncture vine (Tribulus terrestris L.) 1962

14. Nohu (Tribulus cistoides L.) 1963

    (note: Nohu is another example of a plant which is indigenous to Hawaii and would therefore fall under the NPS's protection policy, but is considered a noxious weed by the State where it infests agricultural and recreational areas.)

15. Blackberry (Rubus penetrans Bailey) 1963

16. Klamath weed (Hypericum perforatum L.) 1965

17. Hamakua pamakani (Ageratina riparia K. & R.) 1973

The distribution of these plants, phytophagous insects introduced as biological control agents, and effectiveness of their control are listed in Table 1.

An account of biological control failures in Hawaii would include firebush for which no controls have yet been found. Although introduced insects are established on nutgrass and hairy fleabane, they have likewise not proven effective. Failures of candidate insects in quarantine may be due to faulty handling techniques, natural phenomena such as diapause, disease, mite predators, or parasitism not evident at the time of foreign or domestic export. Candidates which have been successfully propagated and tested in the quarantine insectary and subsequently liberated may not become successfully established due to poor phenological synchrony, missing habitat requirements and environmental resistance such as parasitism, disease, or predator activity.

More successful attempts at biological control of weeds in Hawaii have resulted in partial control of lantana, first documented by Perkins and Swezey (130) and later by Davis and Krauss in 1961 (4), Maui pamakani (14, 15, 16, 129), cactus (58, 129), emex (41), Klamath weed (36), puncture vine (40), and Hamakua pamakani (182). A progress report on the biological control status of these noxious weeds was prepared by Davis (30) and updated as shown in Table 1 under "Remarks".

The paper published by Carpenter in 1944 (25) regarding control of the prickly pear cactus (Opuntia megacantha Salm-Dyck) is of particular significance since it appears to be the first attempt in Hawaii to control plants with a pathogenic fungus. A variety of Fusarium oxysporum Schlecht. emend Sny. & Hans., which was first discovered above Eleele on the east rim of Hanapepe Valley, Kauai (Stephen Au, personal communication), caused a soft rot in both large and small plants. This pathogen could be inoculated directly into the tissue of a healthy plant and successfully eliminate the host, with general tissue collapse occurring within 2 to 5 weeks. When all factors are taken into account, the effort to control prickly pear cactus may be considered the most successful biological control program to have yet been undertaken in Hawaii.

While some success in the biological control of seven noxious Hawaiian weeds have been documented, the dramatic results obtained with three agents introduced for the biocontrol (i.e. biological control) Hamakua pamakani have unfortunately not been published to date. These agents are a plume moth (Oidaematophorus sp.), Hamakua pamakani gall fly (Procecidochares alani Steyskal), and a new species of the phytopathogenic fungus Cercosporella.

The work of Trujillo leading to the utilization of Cercosporella sp. as a biological control agent (182) is of particular importance. It represents the successful use of a pathogenic fungus introduced into Hawaii specifically for this purpose. Trujillo collected the pathogen during an exploratory expedition to Jamaica and the study was conducted at the University of Hawaii Department of Plant Pathology.

Historically, however, and by legal mandate (75), plant biocontrol efforts in Hawaii have been conducted by the Hawaii State Department of Agriculture (HSDA)-Plant Pest Control Branch, which was, and still is, oriented exclusively to entomological biocontrol approaches rather than to the use of plant diseases.

Hamakua pamakani is an aggressive noxious weed of ranch lands, as well as on lands of federal and state domain, occurring at pest levels between 610 and 1372 m elevation. In the past, approximately 130,000 acres of land were plagued by this weed, mostly on ranch lands on the island of Hawaii. Since the introduction of the two phytophagous insects in 1973 and 1974, and of the pathogenic fungus Cercosporella sp. in 1975, Hamakua pamakani has virtually disappeared from some localities (e.g. in the vicinity of Volcano Village), and its density is significantly reduced in others. This observation is supported by photodocumentation and an excerpt from the HSDA, Plant Pest Control Branch, dated February, 1981, which states (77):

> According to the manager of the Palani Ranch, introduced bio-control agents have reduced the pamakani infestation by 80%. Over 800 acres which were infested are now relatively free of pamakani. At Parker Ranch, the combination of herbicides and bio-control agents have eliminated about 50% of the Hamakua pamakani which infested over 900 acres. At Honomalino, nearly all of the pamakani infesting 2,700 acres were destroyed by introduced bio-control agents.

The insects and pathogens are working with good results in Hawaii Volcanoes National Park (HAVO) (personal observation, DG & CD).

Biocontrol of Lantana in Hawaii--A Case History

When an introduced plant becomes established, it very often does so without its natural enemies and may consequently flourish, frequently under normally unfavorable climatic conditions. Its spread may be assisted by man, birds, mammals, wind, and rain runoff. A case in point is lantana, which was purposely introduced as an ornamental in 1858 by William Hillebrand, a physician-botanist who had a great deal of interest in native Hawaiian plants. By 1902 very large areas in Hawaii were occupied by lantana and its spread was attributed to two introduced birds, the spotted or lace necked dove (*Streptopelia chinensis*) and the common mynah bird (*Acridotheres tristis*). These birds reportedly fed avidly on the berries of lantana (130).

Observations by ranchers on the destructiveness of an immigrant scale insect, the greenhouse orthezia (*Orthezia insignis* Browne), on lantana suggested a search for and study of insect enemies of this plant in Central America. This gave rise to a biological control (hereafter referred to by the abbreviation biocontrol) of weeds program that began in 1902 (130). Historically, this was the first attempt to control a weed through this method in the United States, and perhaps in the world (178), and resulted in the establishment of eight of 23 insects imported from Mexico.

In this initial biocontrol effort the candidate insects were carefully studied in Mexico and screened for parasites and predators in Hawaii before release. Host specificity tests in Hawaii were not carried out. Of the eight established lantana insects, two were later found on other hosts. The insects were *Strymon echion* (L.), a minor pest of eggplant, and *Teleonemia scrupulosa* Stal, which has twice been reported feeding on a native Hawaiian tree, *Myoporum sandwicense* Gray (12).

It was determined by Australian and Hawaiian entomologists that introduced lantana insects were not exerting sufficient stress to effectively control the plant. Consequently, the then Hawaii Board of Agriculture and Forestry resumed work on biocontrol of lantana in 1952. An exploratory entomologist, N. L. H. Krauss, began work in Cuba and carried on investigations intermittently throughout tropical America and other regions. In 1953 the Fijian government, the Trust Territory of the Pacific Islands, the State of Queensland and the Commonwealth of Australia joined the Board of Agriculture and Forestry in a cooperative effort (37). John Mann, entomologist of the Queensland Department of Public Lands, joined Krauss in Mexico and carried on investigations there from July 1953 to January 1954. Between 1954 and 1961 Krauss made further investigations in Florida; Mexico; California; Umtali, Zimbabwe (Southern

Rhodesia); Diani Beach, Kenya; and Vitoria, Espirito Santo, Brazil.

These investigations yielded twelve candidate insects which were received in the Honolulu quarantine insectary facility for screening and host specificity tests. Of these, a cossid, Langsdorfia franckii Hubner from Jalapa, Mexico, and a chrysomelid, Octotoma gundlachi Suffrain from Havana, Cuba, failed to propagate successfully and therefore could not be tested for host specificity. Of the ten insects which were subsequently released, the cerembycid Aerenicopsis championi Bates from Mexico, the noctuid Diastema tigris Guenee from the Panama Canal Zone, the tingid Teleonemia vanduzei Drake from Cuba, and the pyralid Blepharomastix acutangulalis (Snellen) from Mexico were never recovered. Aerenicopsis championi did show promise of establishment, but after a generation in the field in Hawaii it was never seen again.

Between 1957 and 1961 the first important break-through in improved biocontrol of lantana occurred between sea level and 610 m elevation on the islands of Hawaii and Maui and up to 244 m elevation on the neighboring island of Molokai. The responsible agents, with the exception of the tingid T. scrupulosa Stal were new introductions. They were as follows (in order of importance):

1. Hypena strigata F. (1957; Kenya, East Africa)

2. Teleonemia scrupulosa (1902; Mexico)

3. Syngamia haemorrhoidalis Guenee (1956; Cuba and Florida)

4. Catabena esula Druce (1955; California)

There was, however, much to be desired in lantana control in the wetter areas of the state. This led to the reintroduction and establishment (in 1961) of the destructive stem and root boring cerambycid from Mexico Plagiohammus spinipennis Thompson in the Kona and Ka'u Districts of the island of Hawaii. The leaf mining chrysomelid Uroplata girardi Pic was also introduced from Vitoria, Espirito Santo, Brazil in 1961 and was subsequently released in Lawai Valley, Kauai (which received an average of 80 inches of rainfall annually).

Beginning in 1963 significant developments occurred, the first of which was the recovery of the leaf mining chrysomelid Octotoma scabripennis Guerin at White Sands, Kailua-Kona. This was the first recovery of this beetle since its reintroduction in 1953-1955. Between 1963-1965 it spread extensively in the Kona District, occurring in both dry and wet habitats and caused considerable foliar damage to lantana on the McCandless Ranch. In June 1965 (4 years after its liberation) the population of U. girardi exploded in Lawai Valley and it was estimated that this insect spread 15 square miles. On Oahu it has also spread extensively on Mt. Tantalus.

The most encouraging development, however, was the spread and damage caused by the lantana borer P. spinipennis at Kukui Paddock, Ka'u District, where field adults were recovered for the first time. According to K. L. S. Harley, Australian research scientist, "A partial survey of the incidence of this insect has revealed that several acres of lantana are under heavy attack. It may be anticipated that within two or three years effective control of the weed may be effected. The position is excellent and should be viewed with optimism" (42). Under Hawaiian conditions, adults appear to be emerging between June and August and possibly later.

Dr. Harley's research area was subsequently disturbed substantially by ranching activities and many of the infested plants were destroyed. A small residual perimeter population remained, however, and P. spinipennis has since spread a distance of 2 linear miles along the highway toward Pahala. This cerambycid is also well established on Hawaii on the Sherwood Greenwell Ranch, Kona, between 610 and 1,067 m elevation, and at Hilo.

In recent years populations of important lepidopterous defoliators of lantana appear to have become stabilized, possibly due to egg parasitism by the wasp Trichogramma sp. and larval and pupal parasites of various other species (these introduced as biocontrol agents many years before). The leaf mining chrysomelids, however, continue to be very active most of the year and have greatly extended their range on Maui and Hawaii. To date there is no evidence of parasitism of these insects, but minor predation by an undetermined organism has occurred in some localities (personal observation, CD).

In 1970 a Peruvian tingid, Leptobyrsa decora Drake, was released at Keokea and Ulupalakua, Maui, and at Kokee, Kauai, and by 1972 was firmly established on both islands. It was subsequently released on Hawaii where it has become established. Its spread, however, is very slow and its evaluation is pending.

It has been 79 years since the first lantana insects were introduced, and, although it has not been an easy task to establish insects that are climatically suited to the wide ecological range of L. camara, considerable progress has been made. The recent introductions have complemented the earlier ones and this has resulted in greater stress on this verbenaceous weed. In drought prone areas lantana in the past has generally managed to recover but with the combination of drought and later insect introductions, considerable dieback and often death of the plants resulted, as was observed on West Molokai, Maui and in some locations on Hawaii. The potential for greater biological control of this weed perhaps could be enhanced by a careful study of phytopathogens which, until recently, had not been given much attention (62).

PREVIOUS EXOTIC PLANT CONTROL EFFORTS IN HAWAIIAN NPS AREAS

The presence of nonnative plants in HAVO and in Haleakala National Park (HALE), on the island of Maui, is widely recognized to be among the most far-reaching and challenging of all resources management problems. Past exotic plant control programs in HAVO have concentrated mainly on firetree and have involved mechanical removal of young plants and spraying the lower stems of older trees with herbicide solutions, particularly with a 4 percent solution of silvex in diesel oil.

Several years of intensive, often full-time, effort by HAVO resources management field crews, aided by Youth Conservation Corps personnel in the summers, have been devoted to the control of this exotic species. Large sums of money and thousands of man-hours were expended in this program, resulting in the destruction of more than 78,000 firetrees. Notwithstanding this effort, firetree populations are well established outside of HAVO and have steadily increased in the park to the point at which present mechanical or chemical control approaches no longer appear feasible, except perhaps in localized work units.

In addition to firetree, mechanical removal of other woody shrubs or small trees, such as Christmas berry, silk oak (*Grevillea robusta* A. Cunn.), koa-haole (*Leucaena leucocephala* (Lam.) de Wit), glory-bush (*Tibouchina urvilleana* (DC.) Cogn.), fuchsia (*Fuchsia magellanica* Lam.), olive (*Linociera ligustrina* Sw.), wild blackberry and raspberry (*Rubus* spp.), and several species of herbaceous plants, has been attempted on a more limited scale. Isolated stands of koa-haole in remote areas have also been sprayed with herbicide from a helicopter with partial (or temporary) success in which population reduction was achieved, although some older trees eventually resprouted following treatment and new seedlings continued to appear.

Herbaceous plants such as ginger (*Hedychium* spp.) have been successfully treated locally with herbicide, notably Tordon 10K, a solid formulation applied to the soil surface above the root zone. In recent years efforts have been concentrated on control or elimination of fountaingrass (*Pennisetum setaceum* (Forsk.) Chiov.) from arid, remote regions of HAVO by spraying clumps with herbicide, or uprooting young plants. While a degree of temporary success has been obtained, it appears that in some areas the rate of new invasion into park lands and reestablishment of this grass in formerly treated areas may indicate the impracticality of such control approaches on an indefinite basis.

Control of other aggressive exotic grasses, such as bushy beardgrass (*Andropogon glomeratus* (Walt.) BSP.) and broomsedge which are particularly abundant in fire-disturbed areas where they themselves create major fire hazards as well as competing with native species (166), has not been attempted due to lack of practical control methods. In such grasslands herbicidal spraying or broadcasting and mechanical removal have often been considered too environmentally disruptive to be useful methods. However, actual investigation of such approaches is necessary for the establishment of definite conclusions.

A limited attempt has been made to locate and uproot vines of banana poka where it has become established in dense rain forest localities; however, the disturbance caused by this activity in these fragile areas was considered excessive. Banana poka is widely dispersed as individual plants throughout the rain forest, and in some areas it forms a dense mat of foliage lying upon and shading out all other plants, including the native trees. Location and destruction of each banana poka plant would be an impractical, labor-intensive control approach requiring continuous surveillance. Even if this were possible, it is doubtful that banana poka could be controlled indefinitely. Since vines of this species become closely intermingled with the forest canopy, spraying with herbicide would likewise not be practical due to the extensive damage to native plants which would undoubtedly result.

Gorse, which occurs as an aggressive species in HALE, has been subjected to systematic poisoning for several years with kerosene. Treatment of young plants is attempted before the flowering stage is reached, thus preventing regeneration of this weed; however, the seed supply already in the soil is large and constant surveillance of infested areas is necessary. Young pine trees arising from those planted in HALE in former years are chopped down and mechanically removed.

The feasibility of herbicidal control of strawberry guava, which grows extensively in exclusive thickets and constitutes a serious problem in the lower Kipahulu Valley region of HALE, was recently investigated (61). Dense strawberry guava stands also occur in the vicinity of HAVO and individual plants of this species, many of which are young saplings, currently occur within the park. Indications are that control of strawberry guava through herbicidal or mechanical removal approaches would require a much greater effort than the park would be capable of producing under current staffing and funding levels.

CONSIDERATIONS FOR BIOCONTROL IN HAWAIIAN NPS AREAS

An understanding of the major interacting factors which aggravate the problem or complicate control efforts should preface any discussion on control of Hawaii's exotic plants. The obvious underlying cause of exotic plant invasion is the direct introduction of these species into Hawaii by modern (since 1778) human activity. During the colonization of Hawaii by American, European, and Asian settlers, plants and animals from these regions were freely introduced. Until relatively recently, little serious regard was given to the detrimental effects of some of these introductions, which had become far more aggressive in their new habitat, due largely to the absence of their natural enemies. Although the state now enforces importation policies enacted to address this problem, unauthorized exotic species are undoubtedly still arriving and becoming established in Hawaii.

An important secondary result of exotic introduction involves the dispersal of exotic plants by exotic animals. Mammals such as feral goats and pigs (the European wild boar) quickly became adapted to Hawaiian habitats and increased prolifically, also in the absence of natural enemies. The succulent fruits of banana poka and strawberry guava for example, are favorite foods of feral pigs. The seeds pass unharmed through the digestive tracts of these animals and become widely dispersed as the animals travel about (45). In addition to seed dispersal, rooting activities of pigs thoroughly disturb large tracts of native plant habitat, often in remote areas of rain forests. This disturbance enables and encourages the invasion of exotic plants which may not otherwise be capable of becoming established in these areas. Thus, effective exotic mammal control appears to be a prerequisite to the successful control of some of the most important exotic plant species.

Likewise, introduced birds, including the Japanese white-eye and the common mynah, are suspected to aid significantly in the spread of exotic plants, such as firetree, which produce seeds in succulent berries. The extensive, uniform dispersal of firetree throughout much of the remote region of HAVO is difficult to account for in the absence of such a dispersal mechanism. Studies are currently underway to determine the feeding activities and capabilities of nonnative birds to pass exotic plant seeds through the digestive tract (native birds appear less likely to be major dispersing agents of exotic plants). Knowledge of such dispersal mechanisms may furnish supplementary avenues which must be employed in conjunction with direct measures for exotic plant control programs to be successful.

Biocontrol approaches for exotic plant species such as those listed above which cannot be controlled entirely through current mechanical or herbicidal means may be considered. The use of plant pathogens or predaceous insects as biocontrol agents, while usually not completely eliminating the target plant species, may effectively stress the population to the extent that it loses its aggressiveness and becomes manageable. Once established, biocontrol agents may distribute themselves throughout the range of the host species, reducing or eliminating the necessity for the labor-intensive effort required for herbicidal treatment or mechanical removal. Effective biocontrol agents may be expected to become a permanent part of the environment, exerting their influence indefinitely.

Factors which contribute to the desirability of biocontrol approaches must be considered carefully since they may also be regarded as negative aspects. Thus, biocontrol often has the aspect of a "double-edged sword." Biological agents may effectively distribute themselves throughout their ecological range and become permanently established. Political barriers, such as those delimiting a NPS area, are of no consequence in restricting the range of such agents. Whereas herbicidal treatment or mechanical removal practices may be confined to specified areas, with no effect on other regions, a pathogen or insect released in a NPS area must be expected to spread freely to all areas where suitable habitat is found. The various interests of the community at large must therefore be fully considered, and biocontrol agents need to be tested so that any released organisms will not adversely affect native species, or be uncontrollable against economically important plants.

Regardless of the precautions taken in any biocontrol program to screen potential agents for pathogenicity or feeding on nontarget plants prior to release, the possibility still exists that such an agent will be released which will, in fact, attack one or more native plants. This is due to inherent limitations in preliminary testing procedures. Practical considerations dictate that native plants selected for testing be those most closely related to the known hosts of the candidate biocontrol agent or those of greatest economic value. The most likely potential hosts are therefore evaluated; however, screening of all native or economically important plants would not be possible.

Space limitations in enclosed growth facilities further restrict testing to representative seedlings or young plants and may exclude mature forms, especially of shrubs or trees, whose sensitivity to attack by a biocontrol agent may change with age. Subtle effects on the physiology of either the test plants or the control organisms resulting from the failure of artificial growth conditions, such as lighting and temperature, to exactly duplicate those of the outside environment, may lead to indications that feeding or pathogenicity would not occur in nature when, in fact, it would.

The reverse situation may also be true in which the artificial conditions of confinement may unnaturally favor the candidate control organism or disfavor the host and thereby indicate virulence which would not occur in nature.

Personnel concerned with culture of plants in greenhouses are commonly aware of particular disease, insect, or mite problems which are serious either inside or outside of greenhouses but are not significant in the opposite situation. As an illustration, the rust fungus *Pucciniastrum epilobii* Otth. was first reported by the senior author to be present in Hawaii, where it attacked leaves of *Fuchsia hybrida* Hort. ex Vilm., causing defoliation (60).

In an effort to evaluate this rust as a possible biocontrol agent for *F. magellanica*, a species which occurs as an exotic in HAVO, it was found that plants of *F. magellanica* grown from cuttings in the HAVO greenhouse could be successfully infected through artificial inoculation methods. However, inoculation of plants of the same species in a nearby outside location did not result in infection (unpublished results, DG). Thus, although preliminary screening in an enclosed facility is necessary to determine indications of pathogenicity or feeding, it does not provide absolute assurance of the host limitations of the agents in question.

Furthermore, since most organisms imported into Hawaii for biocontrol purposes would themselves be exotic, this approach to exotic plant control may pose the philosophical inconsistency with NPS policy of replacing one exotic species by another, or providing a second exotic organism where only one was originally present. According to the viewpoint of some investigators, "biological pollution" has resulted from past attempts to control pests in Hawaii through the introduction of numerous, less host specific insect species. Not only are these insects considered to have been ineffective in controlling particular target pests, they have themselves become established as permanent components of the island fauna (83). In its biocontrol programs, the HSDA is not affected by the dilemma of introduction of exotic organisms to control exotic plants to the same extent as is the NPS due to the different objectives between the two organizations. The HSDA is principally oriented toward improving crop production, with less regard for the exotic nature of organisms introduced for this purpose.

Because of the different objectives between the NPS and various other interests in Hawaii concerning the desirability or undesirability of particular plant species, when the feasibility of successful biocontrol of a given exotic plant species is considered, social and political priorities and interactions as well as the strictly biological factors of the problem must be taken into account. In general, the greater the economic or aesthetic value of a plant species, or the more closely related it is to plants of such value, the more information has been accumulated concerning the diseases or insects that attack them. An inverse relationship therefore exists between the theoretical "arsenal" of insects and diseases available for consideration in biocontrol programs from a strictly scientific standpoint and the actual feasibility of these prospects as viewed from a social or political position.

Such pathogen or insect/host relationships have traditionally been studied from a standpoint of the protection of the host plant rather than from one of controlling its spread. Thus, the potential effectiveness of pathogens or phytophagous insect activities in biocontrol programs is frequently not reported as such in the literature where emphasis is placed on controlling the disease or insect itself for the preservation of the host.

As indicated above, current state law provides the HSDA with authority to set and enforce all plant or animal quarantine regulations and to administer the process whereby any living nonnative plant, animal or microorganism may be imported into the state (74, 76). The presently structured review system includes advisory committees and subcommittees, comprised of representatives of various important agricultural interests, such as the Hawaii Sugar Planters' Association, and those knowledgeable in other areas of environmental concern. These experts and representatives are requested to review formally prepared proposals for the importation of all biological material, including prospective biocontrol agents. The HSDA then officially approves or disapproves importation in accordance with the restrictions and provisions specified by the various review panels. The review process typically requires several months, depending on the availability of individual reviewers and the nature of the importation request.

SPECIFIC EXOTIC PLANTS FOR WHICH BETTER CONTROL IS DESIRED IN HAWAII VOLCANOES AND HALEAKALA NATIONAL PARKS

The HAVO Resources Management Plan (RMP) currently in effect (1981 update) lists the exotic plant species which are not considered possible, or would be impractical, to control entirely by mechanical or chemical methods now available. These, as well as other species not in this category on the RMP but which may also be included, and those occurring as problems in HALE, are as follows:

African tulip (*Spathodea campanulata* Beauv.)

Banana poka (*Passiflora mollissima* (HBK.) Bailey)

Bearded bunchgrass (*Andropogon glomeratus* (Walt.) BSP.)

Broomsedge (*Andropogon virginicus* L.)

Christmas berry, Brazilian holly, or Brazilian peppertree (*Schinus terebinthifolius* Raddi)

Common guava (*Psidium guajava* L.)

Firetree, firebush, fayatree (*Myrica faya* Ait.)

Fountaingrass (*Pennisetum setaceum* (Forsk.) Chiov.)

Giant bamboo (*Dendrocalamus giganteus* Munro)

> note: Although this is thought to be the correct specific epithet, it can only be verified when the plants flower, which may occur on a cycle of approximately 100 years.

Ginger (*Hedychium* spp.)

Glory-bush (*Tibouchina urvilleana* (DC) Cogn.)

Gorse (*Ulex europaeus* L.)

Java plum (*Eugenia cumini* (L.) Druce)

Kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.)

Koa-haole, haole koa, or e'koa (*Leucaena leucocephala* (Lam.) de Wit; synonym: *L. glauca* (L.) Benth.)

Koster's curse (*Clidemia hirta* (L.) D. Don)

Malabar melastome (*Melastoma malabathricum* L.)

Meadow ricegrass (*Microlaena stipoides* (Labill.) R. Br.)

Molassesgrass (*Melinis minutiflora* Beauv.)

Natal redtop grass (*Rhynchelytrum repens* (Willd.) C. E.)

Shoebutton ardisia (*Ardisia humilis* Vahl)

Strawberry guava (*Psidium cattleianum* Sabine)

Wild blackberry (*Rubus penetrans* Bailey)

Wild raspberry (*Rubus ellipticus* Sm.)

Wild raspberry (*Rubus glaucus* Benth.)

Other exotic species such as lantana, Hamakua pamakani, and Maui pamakani are pests in Hawaiian NPS areas but are not listed above since the biocontrol programs discussed earlier conducted by the HSDA and the University of Hawaii have already been implemented and are considered successful, or at least partially so, by some investigators.

Since the primary purpose of this report is to discuss possibilities, limitations, and other aspects of biocontrol from a scientific perspective, pathogens and phytophagous insects associated with the above-listed nonnative plant species in Hawaii for which information is available in the literature are discussed below. However, agricultural interests and other anticipated sociopolitical factors dictate that considerably fewer of these species may actually be acceptable for biocontrol approaches in a practical sense, at least in the forseeable future. Thus, the plants listed above may be divided into three categories:

1. Species which are universally recognized as noxious in Hawaii and for which biocontrol would probably create no serious conflicts.

Firetree
Fountaingrass
Gorse
Koster's curse
Molassesgrass
Natal redtop grass

2. Species which are universally recognized as noxious, but are closely related to other species of economic or other importance (including native taxa) and therefore would require highly specific control agents.

Banana poka
Bearded bunchgrass
Broomsedge
Wild blackberry
Wild raspberry (*R. ellipticus*)
Wild raspberry (*R. glaucus*)

3. Species which are recognized as noxious in local areas but are considered important to other interests elsewhere in Hawaii.

African tulip
Bamboo
Common guava
Christmas berry
Ginger
Kikuyugrass
Koa-haole
Strawberry guava

The status of other species is uncertain and not possible to clearly categorize.

Banana poka.--The use of larvae of one or more species of heliconid butterfly from South America has been discussed informally for several years in banana poka control efforts, although an active program has never been undertaken. A number of years ago, correspondence was also exchanged between the Pacific Southwest Regional Office of the U. S. Forest Service and Dr. L. E. Gilbert at the University of Texas at Austin, an expert in this group of insects. Dr. Gilbert and his associates (193) were (and continue to be) optimistic in their opinion that one or more species of these butterflies could provide significant control of banana poka in Hawaiian forests with little probable damage to passion fruit (_P. edulis_ f. _flavicarpa_ Degener). He, with his students and associates, expressed a desire to pursue such a study and submitted a project proposal including a tentative budget for this work.

Interest in this project appeared later to have been dropped by the Forest Service, probably due to the lack of sufficient support funding. HSDA officials (personal communication, DG) are aware of this effort as well as of other insects associated with _Passiflora_ spp. They have expressed their willingness to supervise quarantine testing and to cooperate with interested federal agencies, the U. S. Forest Service and the NPS in particular, if funding could be made available through the state legislature. Some funds were provided to the State Division of Land and Natural Resources (DLNR) by the 1981 legislature, and Dr. Robert Pemberton, an exploratory entomologist with the U. S. Department of Agriculture, was contracted to search for beneficial insects in Peru and Colombia. The results of his expedition, conducted during the winter and spring of 1982, have not yet been fully evaluated.

Valero and Viana reported chlorotic spotting of _P. mollissima_ caused by a species of the cicadellid insect _Empoasca_ (189). Few apparently highly virulent diseases are known to occur on banana poka; however, the following diseases have been reported: A stem and leaf spot caused by _Colletotrichum gloeosporioides_ Penz. (185), and _C. passiflorae_ Stevens & Young, which was originally reported from Hawaii and causes anthracnose on leaves and fruit (171). Current observations indicate that this disease is not particularly severe, however, in areas where it has been found. Other Passiflora species, as well as P. mollissima, are attacked by the rust Puccinia scleriae (Pazschke) Arth. This rust reportedly requires an alternate host, however, a nut-rush (Scleria spp.) to complete its lifecycle (185) and would appear in this situation not to be practical as a biocontrol agent since the repeating stage occurs on the alternate host.

Numerous reports are present in the literature of diseases and insects of the edible Passiflora species (6, 11, 20, 26, 55, 85, 97, 104, 109, 117, 132, 134, 137, 142, 156, 170, 172, 183), or other species (97, 125, 170). These are listed but are not discussed individually here, since the host ranges and effects on P. mollissima itself remain to be ascertained for most, if not all, of these organisms. However, particular mention should be made of a recent report by Hiam (79) which refers to and illustrates the passionfruit butterflies Heliconius melpomene and H. erato, which are miilerian mimics and which are consistently rejected by birds. Mention should also be made of a serious vascular wilt disease of P. edulis reported from Australia and New Zealand, with an associated collar or crown rot, caused by Fusarium oxysporum f. passiflorae Gordon apud Purss (7, 65, 110, 117, 138, 139). Fusarium wilt diseases are well known among researchers in this field to be highly virulent as well as usually quite host specific. Susceptibility of P. mollissima to this disease cannot be predicted on the basis of reports from other host species and would require actual testing.

A circular written for the benefit of those interested in growing or maintaining passionfruit in Hawaii describes a number of pests of this plant and recommends control measures (119). However, none of these occurring locally has yet demonstrated the ability to attack and significantly limit the growth or spread of banana poka.

The attack of P. foetida L. by Haplosporella passifloridia Pande and the virus disease of this species reported by Pande (125) and Leggat and Teakle (97), respectively, are of particular interest since this host also occurs in Hawaiian NPS areas as an undesirable exotic plant, although of less current importance as a threat to native ecosystems than is P. mollissima.

Firetree.--A fungus disease of Myrica faya was observed in the 1950s by an exploratory entomologist from Hawaii, Mr. Fred Bianchi, during an expedition to the native habitat of M. faya (the Azores, Madeira, and the Canary Islands) conducted to locate potential biocontrol agents for this plant. The disease appeared in field observations to be causing severe dieback among entire stands of firetree and was considered an ideal candidate biocontrol agent for firetree in Hawaii (F. Bianchi, personal communication, DG; 17). The fungus was later identified by plant pathologists in Portugal as Dothiorella berengeriana Sacc. (N. F. S. Azevedo, personal correspondence, DG; 9, 148). Attempts at that time to introduce the fungus into Hawaii were not successful due to indications resulting from testing in Portugal that the fungus would also attack certain economically important plants, although such attacks on similar plants under the natural conditions of its native habitat had never been observed by the local residents, as determined by Mr. Bianchi.

Krauss (94) summarized adequately the earlier rather extensive efforts by himself and other entomologists to locate insects in the native regions of firetree, and also those associated with southern waxmyrtle (*M. cerifera* L.) (native to the southeastern U. S.), which may have proven promising as biocontrol agents for *M. faya* and to introduce them into Hawaii. Southern waxmyrtle is closely related to firetree and also occurs as an exotic plant in Hawaii, although this species appears not to be aggressive and does not pose a threat to native ecosystems. Several such collections of insects representing various species were made but these could not be propagated successfully or they otherwise proved ineffectual in controlling firetree in Hawaii. Krauss (94) also discussed pathogenic fungi and other organisms reported on *Myrica* spp., but no attempt was made to evaluate these as potential biocontrol agents in Hawaii.

Ruehle (150, 151) reported an algal leaf spot on *M. faya* in Florida. This disease was presumably caused by the same, or a similar algal species to the one already occurring in Hawaii, where it causes leaf spots on common guava and other plants. No effect on firetree in Hawaii has been noted, however, suggesting that this disease may be of little or no importance on this host species locally under normal environmental conditions.

Diseases reported on other *Myrica* species but which have not been tested for pathogenicity on *M. faya* include the rusts *Gymnosporangium myricatum* Fromme (50), *G. ellisii* (Berk.) Ell. (53), *Cronartium comptoniae* Arthur (169), and others that form witches' brooms on the primary hosts (48, 49). A wood-decaying fungus, *Ptychogaster cubensis* Pat., has been reported on living stems of southern waxmyrtle (28). Other reports include *Cytospora umbrina* (Bon.) Sacc. on *Myrica* species in Russia (67), and *Lophiostoma desmazierii* Sacc. et Speg. as a new species on *M. faya* in Portugal (101).

Broomsedge and bearded bunchgrass.--*Andropogon* spp., particularly *A. virginicus*, is reported in the literature (27, 185) to be parasitized, mainly in the southeastern U. S. where it is native, by several species of rust and smut fungi: *Puccinia andropogonis* Schw., *P. ellisiana* Thuem., and *Uromyces andropogonis* Tracy (cause leaf rusts), *Sorosporium ellisii* Wint. (head smut), *S. everhartii* Ell. & Gall. (seed smut), *Sphacelotheca seymouriana* Clint. and *Sphacelotheca occidentalis* (Seym.) Clint. (head or seed smut), and *Ustilago striiformis* (West.) Niessl (stripe smut). The rust fungus *Uredo andropogonis-gayani* Eboh has been recently reported to attack *A. gayanus* Kunth in Nigeria (52). The most common rust fungus attacking _A. gayanus_ and _A. tectorum_ Schum. & Thom. in Nigeria is reported to be _Puccinia agrophila_ H. Syd. (27, 52). Its effects on either of the two exotic _Andropogon_ species in Hawaii remain to be ascertained.

Both the rust and smut groups of fungi include some of the most important and destructive plant pathogens known. The rusts and most of the smuts are obligate parasites; that is, they will grow only on living host plant tissue and cannot be cultured on artificial media. Although this may be regarded as a disadvantage in programs where it is desirable to culture large quantities of inoculum for widespread dispersal or mass inoculation, both groups of fungi, but the rusts in particular, are generally noted for their narrow host ranges. The smut _U. striiformis_ is known to attack a number of grass species and to be quite nonspecific in its host range, however.

Another factor that must be considered among heteroecious rust fungi is the requirement for an alternate host species for completion of the life cycle. It is fortunate that in most incidences the uredinial, or repeating stage, occurs on the _Andropogon_ host. In regions with mild climates, such as Hawaii, this stage may potentially cause repeated infections indefinitely without the necessity of the alternate host. The leaf spot fungus _Septoria andropogonis_ J. J. Davis has also been reported to attack members of the genus _Andropogon_ (185).

In addition to these fungi, a white grub (beetle larva) has been observed feeding on the roots of _A. bicornis_ L. in Colombia and appears to control this species in that region to the extent that this grass is not considered the problem that it otherwise would be (J. M. Spain, personal communication, DG; 168). The grub has been tentatively identified as most likely belonging to the family Scarabaeidae, subfamily Melolonthinae; however, the specific identification is still pending.

Although the scope of this report is basically limited to control with biological agents, it may be informative to note that cultural and chemical methods of broomsedge control (100, 131, 175, 190) have also received considerable attention in studies conducted primarily in the southeastern U. S. where it occupies old or abandoned fields, often with poor soil. Rice (146) also provided evidence that allelopathic characteristics of broomsedge may be á major factor in the ability of this grass to maintain almost pure stands in old fields.

Guava, strawberry guava, waiawi, and Java plum.--Each of these plants belongs to the family Myrtaceae, which also includes several other exotic plants in Hawaii such as rose apple (_Eugenia jambos_ L.), which is also a problem in HALE's Kipahulu Valley, paper bark tree (_Melaleuca leucadendra_ (Stickm.) L.), brush box (_Tristania conferta_ R. Br.), and _Euclayptus_ spp. to name a few. Some of the latter species also occur in NPS areas, although these are not currently considered to present nearly as severe a problem as do common and strawberry guava. Additionally, the most common and conspicuous native tree species in forests of both HALE and HAVO, ohia-lehua (Metrosideros collina (J. R. & G. Forest.) Gray subsp. polymorpha (Gaud.) Rock, also belongs to the family Myrtaceae.

This relationship, as well as the fact that eucalyptus is an important reforestation tree in Hawaii and that considerable public interest exists in the possibility of a common guava industry (196), would appear to significantly reduce the feasibility of biocontrol efforts for the problem myrtaceous species. The value and usefulness of strawberry guava fruit has been promoted in the past by horticultural interests (155), and, although this tree is not actually cultivated for its fruit in Hawaii to any major degree, its occurrence in the wild is welcomed and encouraged by many local residents. This species is also used frequently for landscaping. It is interesting to note that as one of the points presented in favor of strawberry guava cultivation, Schroeder and Coit stated: "There is no record of any disease affecting this plant" (155).

Aside from the social implications of guava, strawberry guava, and Java plum control with biological agents, the following information is available: A parasitic alga of the genus Cephaleuros, which commonly causes leaf spots in Hawaii on common guava and other plants (personal observation, DG; 141), has also been reported on common and strawberry guava, among many other species, in Florida (105, 106, 151). Marlatt and Campbell (106) stated that the disease could severely diminish photosynthetic leaf surface, and apparently could cause premature defoliation. It is doubtful that the effects of this disease in reducing the vigor of common guava in Hawaii have ever been measured or considered in a scientific study.

Yen (202) reported a new disease caused by Cladosporium psidiicolum Yen on common guava. Botryosphaeria ribis var. chromogena, which causes twig dieback, was reported on guava, among many other hosts from Hawaii (185). Leaf and fruit spots or anthracnose caused by Cercospora psidii Rengel and Colletotrichum gloeosporioides (which are recognized as quite nonspecific pathogens) have also been reported from Hawaii (185). Clitocybe tabescens (Scop. ex Fr.) Bres., a common root rotting pathogen of many woody plants, has been reported on common guava in Florida (185). The rust Puccinia psidii Wint., whose uredinial, or repeating, stage has been reported both on species of Eugenia and Psidium in Puerto Rico (185), is a disease of particular interest to this discussion.

Gupta and Chatrath (66) investigated the mutability of the anthracnose fungus Colletotrichum gloeosporioides on guava fruits. This organism was also reported to attack Passiflora fruit, and is familiar to plant pathologists as the anthracnose-causing pathogen of many similar fleshy fruits.

Ooka (123) and other authors cited by him have reported fruit rots of guava in Hawaii caused by various more or less nonspecific fungi such as Rhizopus stolonifer (Fr.) Lind. and Mucor hiemalis Wehmer., and guava fruit rots caused by other fungi have been observed elsewhere (136, 143, 144). These are considered here to be of somewhat less potential value in biocontrol efforts than is their importance in the degradation of marketable fruit. However, their effects may conceivably reduce seed production or viability in some instances.

Entomologists in Egypt have reported several scale insects which attack Psidium guajava (54). Of these, the most serious were Pulvinaria psidii Mask. and Saissetia coffeae Wlk. P. floccifera Westw. and Coccus elongatus Sign. were also found on this plant. Much of the damage resulted from colonization of the sooty exudate of the scale insects by a black mold which inhibited plant respiration and photosynthetic processes. Each of the above-named insect species, as well as many others associated with guava, are known to be already present in Hawaii and are considered pests of guava (J. W. Beardsley, personal communication; DG). Their effects in actually limiting the spread of guava are apparently minimal.

It is interesting to note that P. psidii was also found to attack Schinus terebinthifolius in the same way throughout the year (54). Becker (13) reported that the caterpillars of two related lepidopterous species feed on the foliage of common guava in Brazil. The paper included figures indicating considerable damage to the leaves resulting from the feeding of at least one of these species.

Fountaingrass and kikuyugrass.--Literature on pathogenicity and predation of members of the genus Pennisetum is voluminous since it is a large genus with many highly important economic crops as pearl millet, P. typhoides (Burm. f.) Stapf & C. E. Hubb. (synonym: P. americanum (L.) K. Schum), which is widely cultivated in India, Africa, and throughout other warmer regions of the world. Although an attempt to document completely the diseases and insects attacking these crops would be impractical, a representative list of references may be informative (3, 19, 43, 86, 88, 96, 122, 127, 128, 145, 153, 154, 157, 160, 161, 163, 179, 191, 197). The possibility exists that at least some insects or diseases recorded on economic Pennisetum species under cultivation may also attack P. clandestinum and/or P. setaceum. A caution should be emphasized, however, that these are listed merely to point out conjectural relationships rather than to imply more than is presently known about them. Tests on the target host plants may or may not yield promising results.

Kikuyugrass, as a pasture species of some value, and also as an occasional unwanted invader on the other hand, has also received some direct investigation. Wong (201) reported a yellows disease of this grass caused by a phycomycetous fungus whose specific identity was uncertain. Muchovej (112) described a new, rather severe leaf spot disease of P. clandestinum caused by Drechslera bicolor (Mitra.) Subram. & Jain (synonym: Helminthosporium bicolor Mitra.) in Brazil. Insects attacking kikuyugrass include Frosapia distanti in Costa Rica (56) and the common armyworm (Pseudaletia convecta Walk.), a general grass feeder, in Australia (57). Archibald et al. (8) reported a beetle, Heteronychus arator, in kikuyugrass pastures in New Zealand of sufficient importance that efforts to control it were justified. Several insects of general host ranges such as grass webworms, cutworms, and armyworms are already known to be present in Hawaii on kikuyugrass and are considered pests by ranchers. An armyworm, Pseudoletia unipuncta (Haworth), was a very important pest of kikuyugrass in Hawaii until it was controlled biologically by Apanteles militaris (Walsch.), which was introduced from the U. S. mainland for this purpose.

As was noted in the discussion on Andropogon, chemical control measures have also been tested in situations where these grasses were considered undesirable. Similar work with kikuyugrass appears to be of sufficient importance that mention of it may again be useful. Kilavuka and Magambo (89) reported tests with the herbicides dalapon and paraquat in controlling this species in Africa, where it is native. Rowe and O'Connor (149), working in New Zealand, tested the effectiveness of the relatively newly developed experimental herbicide tetrapion in the control of several rhizomatous grasses, including P. clandestinum. In HAVO, Kageler and Gardner (87) determined that the herbicide Roundup (glyphosate) showed promise of giving effective kikuyugrass control without seriously damaging most of the native species associated with kikuyugrass stands.

Blackberry, raspberry, and other Rubus species.--A great number of pathogens has been reported for this large group of plants (51, 185) due in part to their economic value in other regions and their widespread distribution. Unfortunately, most of these pathogens are known to have rather general host ranges and will attack many members of the genus Rubus as well as those of other genera. Examples are available in the literature, however, of apparently successful control of undesirable Rubus species, such as the bramble R. fruticosus var. bergii Ch. & Sch., which was parasitized by the bramble rust Kuehneola uredinis (link) Arth. (192). Also, R. constrictus Lef. et M. and R. ulmifolius Schott. are attacked by the rust Phragmidium violaceum (Schulz) Winter which has been observed to be an effective control agent of these plants (73). This rust has been employed in blackberry control programs of Chile with encouraging results (73, 120, 121).

Tillyard (180) listed a number of insects known from other countries which he suggested should be studied for the possibility of biocontrol of blackberry (referred to only as Rubus sp.) in New Zealand. The insects were discussed categorically according to the plant regions affected, including those which attacked the crown or stem by boring or forming galls, those which attacked the twigs, those which attacked the leaves and shoots, and those which attacked the flowers and fruits. Of all insects listed, the buprestid beetle Coroelus rubi L. was considered the most promising potential biocontrol agent for blackberry. This beetle was reported to destroy up to 60 percent of the new blackberry stems in southern Europe in certain years (180). As a further advantage, C. rubi was not observed to attack raspberry, or any other members of the Rosaceae except occasionally the long runners of particular rose varieties (180).

In addition to the work of Tillyard, Bruzzese (21) has comprehensively summarized the large number of insect and mite species associated with Rubus spp. in Victoria, Australia. Biocontrol of Rubus has been restricted in this area by the lack of host specificity among the parasites. Nakao (113) reported four insect species from the U. S. mainland which were introduced to Hawaii by Noel Krauss between 1963 and 1967 for the control of R. penetrans. Of these, three became established but have not resulted in significant control.

Christmas berry.--A number of diseases has been reported to attack S. terebinthifolius (185). However, as is the case among the members of the genus Rubus, most of the pathogens are known to have wide and nonspecific host ranges. These include Armillaria mellea Vahl ex Fr., Verticillium albo-atrum Reinke & Berth., Phymatotrichum omnivorum (Shear) Dug., Diaporthe sp., and Botryosphaeria ribis (Tode ex Fr.) Gross. & Dug. The latter two pathogens were reported from Hawaii, where their effects are not obvious at present. Sphaeropsis tumefaciens Hedges, which causes galls on stems, has recently been reported on S. terebinthifolius, the latter as a new host in Florida (107), although the authors also indicated that the virulence of this fungus did not appear sufficient to be effective in controlling Brazilian peppertree (Christmas berry) in that locality.

A newly reported leaf spot disease of S. terebinthifolius has also been reported from Egypt (158). Recent reports of predation and parasitism of species related to S. terebinthifolius include a new homopterous insect which is a pest of S. tebernanthifolius (S. terebinthifolius ?) in Pakistan (1) and the fungi Ptychogaster cubensis and Xanthochrous rickii Pat. on S. molle L. in Morocco (103). As mentioned in the discussion of the history of biocontrol efforts in Hawaii, Krauss (93) described past efforts by the HSDA to introduce insects for the control of Christmas berry in Hawaii. He discussed three predatory insect species that had already been introduced, none of which has apparently since proven significant in control of this plant. He also recorded a rather extensive list of additional insects, representing several orders, most of which had been observed on Christmas berry in Brazil. At the time Krauss' report was published, these had not yet (and presumably have not at present) been further considered for biocontrol purposes in Hawaii. Beekeepers in Hawaii consider Christmas berry a highly desirable source of nectar for honey production and would presumably oppose any further attempts at biocontrol.

Gorse.--This woody leguminous species with sharp, thistle-like spines was introduced to new Zealand from England early in the nineteenth century where it was planted in hedges to contain livestock. It has since escaped from its original planting sites to become a major noxious weed problem in that country. Thus, much attention has been devoted to the control of this plant through the use of herbicides, burning, mechanical removal, and biocontrol approaches in New Zealand. Literature on various aspects of gorse control as well as references to its biology and ecological relationships with native plants, has been recently summarized by MacCarter and Gaynor (102).

A seed weevil (*Apion ulicis* Forst.), which had been reported by Tillyard in 1927 (180) to successfully reduce the numbers of viable gorse seed in England and which was regarded as a significant potential biocontrol agent in New Zealand, was later introduced into that country for this purpose. This insect was recently reported (102), among eight other insects, to be well established on gorse in New Zealand. Notwithstandng this, however, *A. ulicis* does not now appear to be controlling the spread of gorse significantly. Only the cottony cushion scale (*Icerya purchasi* Mask.) and the lemon tree borer (*Oemonia hirta* (F.)) have been observed to cause significant damage to gorse in New Zealand (102). Other insects, such as the stem boring weevil *Apion scutellare* Kirby and a leaf feeding moth (*Agonopterix ulicetella* (Stnt.) are presently being considered for possible introduction to New Zealand as biocontrol agents. As noted in Table 1, both *Apion ulicis* and *A. scutellare* have already been introduced into Hawaii, the former to control gorse, where it is established but is less than completely effective. *A. scutellare* was introduced specifically to control gorse but did not become established on this lant in Hawaii.

Bamboo.--Cummins (27) described a number of rust fungi which parasitize various species of bamboo belonging to the genera *Bambusa* and *Dendrocalamus*, several of which may be potential candidates for biocontrol. Those listed from hosts of the latter genus are *Dasturella divina* (Syd.) Mundk. & Khes. and *Uredo dendrocalami* Petch from *D. strictus* Ness in Ceylon and from *D. latiflorus* Munro in China. *U. ditissima* Cumm. is reported from *D. latiflorus* in the Philippines and Taiwan.

Baradze (10), whose work was reported entirely in Russian and was therefore not reviewed for this report personally, discussed the fungus *Coniosporium bambusae* Sacc. as the causal agent of a wilt disease of bamboo shoots, presumably in the Philippines. The bamboo mosaic virus, relatively recently reported from Taiwan to attack members of the genera *Bambusa* and *Dendrocalamus*, was discussed by Lin et al. (99). However, among the many bamboo species tested for susceptibility to bamboo mosaic, D. giganteus was among those which was reported to be resistant.

Numerous insect species are recorded in the literature (re. Review of Applied Entomology) to be associated with various types of bamboo in several tropical countries. Slater (165), in a recent review paper on the host plant relationships of chinch bugs discussed a number of these species on bamboos. The degree to which each of these is damaging to its host is frequently not revealed in the literature and must be individually ascertained. Many insects are capable of coexistence with their hosts under normal environmental conditions with a minimum of damage and are only infrequently recognized as pests following disruptions of natural balances by rare coincidences of events.

An aphid, Oregma bambusae Buckton, referred to as the bamboo sap-sucker (162), is known to attack several species of bamboo in India. Among its hosts is D. giganteus, the presumed specific identity of the bamboo occurring in dense stands in the Kipahulu Valley region of HALE. The extent to which this insect may impact giant bamboo populations in India was not discussed by Singh and Sivaramakrishnan. The insect Asterolecanium pseudomiliaris Green was recently collected for the first time from bamboo leaves in Hawaii (Oahu) (186), although no destructive effects were noted. Several other scale insects of the genus Asterolecanium are also known to be present on bamboo in Hawaii, and many additional species too numerous to list occur on bamboos in Asia. Most of these insects have a wide host range such that their value as biocontrol agents appears nil (J. W. Beardsley, personnel communication; DG).

Koster's curse, Malabar melastome, and glory-bush.--Members of the tropical American family Melastomaceae, and Koster's curse in particular, are recognized by the HSDA as representing a threat not only to native forests but as competitors for agricultural land as well. At present, Koster's curse presumably does not occur on park lands; however, the lower, wet elevations of both HAVO and HALE appear to be suitable habitat for this exotic. Since the destructive potential of this plant is already evident in other regions of Hawaii, the NPS is committed to its control. An active biocontrol program against this noxious weed has been pursued by the state for some time (78). In April, 1979, an HSDA exploratory entomologist departed on an expedition to several Central and South American countries to search for biocontrol candidates for this, and also for an insect the spiraling whitefly, a recently introduced pest in Hawaii. in Hawaii. During this period, various lepidopterous (butterflies and moths) and coleopterous (beetles) specimens were collected and shipped to Hawaii for propagation and testing in the HSDA quarantine facilities. A few of these were Lius sp. (Buprestidae), an undescribed species of Pantoteloides (Curculionidae), Mompha trithalama (Momphidae), Druentia inscriba (Noctuidae), and Antiblemma acclinalis (Noctuidae).

This project continued and occasional new shipments were received until June, 1981, at which time all of the candidate biocontrol insects maintained in the HSDA insectary died (78) and were not replaced with new shipments of the same species. The HSDA maintains its interest in this project, however, and through a cooperative agreement with the State Forestry Division, DLNR, screening and specificity tests of other control candidates will be conducted by exploratory entomologist Robert Burkhart during his 1-year assignment in Trinidad, West Indies. He will operate out of the CIBC station (from June 1982 until June 1983) and will ship to Hawaii for further study those candidates which show promise in controlling Koster's curse.

It is interesting to note that in 1957 Thistle (178) predicted optimistically that the thrips Liothrips urichi Karny (Table 1) would very likely be successful in preventing Koster's curse from becoming a rangeland pest in Hawaii. This insect, which limits flower and fruit production, was first imported to Fiji by the entomologist H. W. Simmonds where it was reported to have given excellent control of Koster's curse. This success led to its introduction to Hawaii for the same purpose. Although it has become established and does contribute to control of Koster's curse in some regions of Hawaii, its effectiveness there has not attained the degree indicated in Fiji. Wayne Gagne (personal communication, DG) has indicated that in a recent visit to Fiji (1981), he observed Koster's curse to be quite abundant. The Lepidopterous insect Blepharomastix ebulealis (Guenee) was also introduced for Koster's curse control in 1970 (Table 1), however, the effects of this defoliator have not been adequately evaluated to date. As noted above, further efforts to control this noxious exotic species in Hawaii are desirable.

Very few diseases or disease-like conditions of C. hirta have been reported, and those that have been were caused by members of the ubiquitous nematode genera Heterodera and Meloidogyne, and by the black mildew Irene melastomacearum (Speg.) Toro (185). None of these disease agents would likely prove practical in a biocontrol program for Koster's curse.

Other exotic melastomaceous species occurring within, or near, Hawaiian NPS areas are glory-bush (Tibouchina urvilleana (DC.) Cogn. synonym: T. semidecandra (Shrank & Mart.) Cogn.), Indian rhododendron (Melastoma malabathricum L.), and pearl flower (Heterocentron subtriplinervium (Link & Otto) A. Br. Bouche). Each of these is a shrub with attractive, showy flowers. Glory-bush presently occurs in dense thickets in Volcano Village, which adjoins the boundary of HAVO, and although this species occurs within the park itself only as isolated plants, its ability to spread aggressively is obvious. With its large, bright purple flowers, glory-bush is frequently regarded by vistors to HAVO as representing the "exotic" (i.e. unusual, novel) vegetation expected in a tropical rain forest. One insect, Selca brunella Hampson, which was purposely introduced to control Indian rhododendron and glory-bush, is currently established on glory-bush in the Volcano area.

Mechanical removal of flowering shrubs such as glory-bush and fuschia, which had actually been planted in HAVO as a beautification measure in former years (44), is the present control approach. Such visible eradication activities involving mechanical or chemical methods may also serve as an interpretive aid in bringing the purpose of the NPS and its exotic plant control policies to the attention of park visitors and the public in general.

Ginger.--White ginger (Hedychium coronarium Koenig in Retz.), yellow ginger (H. flavescens Carey in Roscoe), and kahili ginger (H. gardnerianum Roscoe), red ginger (Alpinia purpurata (Vieill.) K. Schum.), and wild ginger (Zingiber zerumbet (L.) Roscoe in Sm. all occur as exotic plants in Hawaiian NPS areas. White, yellow, and kahili gingers are particularly undesirable in natural areas since they form dense, exclusive stands with extensive tuberous rootstock systems in native rain forest habitats, where they have escaped from cultivation. Various ginger species are valued as the source of commercial ginger (i.e. cardamon, Elettaria cardamomum (Roxb.) Maton) or for their exceedingly fragrant and/or showy blossoms.

Many of the diseases of ginger were originally reported from Hawaii and include leaf spots, caused by Coniothyrium zingiber F. L. Stevens & Atienza (185) and by Phyllosticta zingiberis F. L. Stevens & Ryan (171), a root rot caused by Pythium butleri Subr. (185), and a rhizome rot caused by a species of Fusarium (126). Trujillo (181), working with commercial ginger (Zingiber officinale Roscoe) in Hawaii, discovered a new forma specialis of the wilt pathogen Fusarium oxysporum which he designated F. oxysporum f. zingiberi Truj. and characterized as causing a serious yellows (vascular wilt) and rhizome rot of this species. Subsequent inoculation and host specificity tests of this pathogen, however, indicated that white ginger was not affected as were varieties of edible ginger. Sivanesan and Gibson (164) described an important leaf spot disease of turmeric (Curcuma domestica Valet.), a member of the ginger family Zingiberaceae in India, Burma, and Japan. The disease was caused by Taphrina malculans Butler, which, with a second disease caused by Colletotrichum capsici (Syd.) Butl. & Bisby, were defined as the two important leaf diseases of this plant in these regions.

Mirid bugs of the genus Ragwelellus are known which feed on gingers and related plants in the New Guinea region, although their host specificity is uncertain. Smith (167) discusses one (R. horvathi Poppius) which is considered a pest of cardamon, and is also found on members of the Zingiberaceae, Musaceae (bananas), and Comelinaceae.

Hawaiian entomologists are aware of a number of insects which are associated with species of ginger in New Guinea and perhaps similar localities of the Pacific (Wayne Gagne, personal communication; DG). The potential of these insects in biocontrol programs against the exotic ginger species in Hawaii is not yet known and remains to be investigated.

Koa-haole.--*Leucaena leucocephala* has been reported to be attacked by the leaf spotting fungus *Exosporium leucaenae* F. L. Stev. & Dalb. and by *Botryosphaeria ribis* var. *chromogena* Shear, N. E. Stevens & M. S. Wilcox. This species was reported from Hawaii to cause twig dieback on a wide variety of hosts. Its current effect on koa-haole is not considered significant. The rust *Ravenelia leucaenae* Long has been observed infecting another member of the genus *Leucaena* in Texas (185). Its pathogenicity or virulence on *L. leucocephala* apparently remains to be tested.

A leaf spot incited by the fungus *Camptomeris leucaenae* (Stev. & Dalb.) Syd. has recently been reported from Colombia (98), where it has caused severe defoliation of *L. leucocephala* trees and was regarded as a serious threat to this host species in that country. In combination with secondary organisms, a dieback of these trees also resulted from infection with *C. leucaenae*. This fungus therefore appears to be of potential value in a biocontrol program. A new wilt-type disease of *L. leucocephala* seedlings and of older trees caused by *Fusarium solani* (Ell. & G. Mart.) L. R. Jones & Grout has recently been reported from the Philippines (140).

At least four destructive, accidentally-introduced insects are presently established on koa-haole in Hawaii. These include the koa-haole looper (*Anacamptodes fragilaria* (Grossbeck)), the black twig borer (*Xylosandrus compactus* (Eichhoff)) with its associated fungi, the koa-haole moth (*Semiothisa infusata* (Guenee)), and the koa-haole seed weevil (*Araecerus levipennis* Jordan). The lepidopterous insects often cause complete defoliation of koa-haole covering many square miles of western Kauai and western Oahu (personal observation, CD).

RESEARCH AND RESOURCES MANAGEMENT CONCERNS

Of the plants discussed above, those of lowest economic or aesthetic value in Hawaii or whose biocontrol programs are otherwise likely to encounter the greatest support may be banana poka, gorse, and firetree, which have long been recognized as noxious species by the HSDA (77). Firetree occurring on ranchland continues to be the object of an active control program by the State of Hawaii, Plant Pest Control Branch, which is presently engaged in control efforts of this species on ranchlands and in state forest reserves. Trees are treated with herbicide (Tordon 22K) or are mechanically grubbed out with bulldozers (Robert Kami, personal communication, DG; 77).

The *Andropogon* species, as well as the other grasses listed except kikuyugrass, are of little or no economic value in Hawaii and would meet minimal opposition to biocontrol efforts if it were not for their relationship, as grasses, to sugarcane (*Saccharum officinarum* L.), Hawaii's most important crop. *Andropogon*, in particular, is classified in the same tribe as sugarcane (80) as well as the rare native grass *Ishaemum byrone* (Trin.) Hitchc. which occurs in HAVO. On the other hand, a high degree of host specificity is frequently found among the plant rusts, which comprise many of the pathogens of these grasses.

Banana poka likewise has no economic value, and would encounter little opposition as a candidate for biocontrol except for its relationship to *Passiflora edulis* Sims, the edible passionfruit, which grows wild in Hawaii's lowlands and is widely valued by Hawaii's people. Passionfruit has been grown commercially on a limited scale, but its cultivation is relatively insignificant to Hawaii's overall agricultural economy. Banana poka is a high elevation species and is not classified within the same subgenus as *P. edulis* (90, 108). It may therefore be feasible to locate a biocontrol agent with sufficient host specificity to selectively attack only banana poka. As mentioned above, HSDA personnel (personal communication, DG) have expressed their desire to undertake such an effort if funding is made available through appropriation by the state legislature.

Although wild *Rubus* species are also valued by individual residents for their fruit, they are generally regarded as noxious weeds in pasture and rangeland by the HSDA (77) and would therefore be candidates for biocontrol efforts (as they have in the past). Two native *Rubus* species occur in Hawaii, *R. macraei* Gray and *R. hawaiiensis* Gray, which would require careful testing for host specificity of all potential biocontrol agents to establish the safety of these native species from excessive attack.

Other plants listed, particularly guava, which is widely valued among Hawaii's residents for its fruit (196), and kikuyugrass, an important pasture grass in Hawaii (194, 195), the species of ginger and other ornamentals would most likely be very difficult to attempt to control through biological means due to public opposition or conflicts with other interests. As mentioned above, Christmas berry is valued for honey production by beekeepers who would likely oppose attempts at widespread control (HSDA, personal communication; DG).

Koa-haole, which now grows in dense stands on vast acreages of dry lowlands throughout the Islands, is a preferred forage of livestock and has been the subject of propagation and lant breeding programs in Hawaii to improve its quality and usefulness (2, 18, 177, 188). Since it has obviously exceeded its intended range in many areas and has spread aggressively, the relative value of this species is uncertain at present, particularly regarding the degree of support a biocontrol program in Hawaii would receive.

Taking into account the existence of potential pathogens and insects available for consideration from a scientific standpoint and evaluating these with regard to the likelihood of their success from a sociopolitical approach as well, the most expedient action in initiating biocontrol projects would be to test potential agents with high probability for success, and which have already been identified against plants which are recognized by the state as well as by the NPS to be noxious weeds. Such a program would be expected to receive wide public acceptance. Any successes with these projects would serve to establish the feasibility of an NPS biocontrol program. Biocontrol projects in which exploratory expeditions must be conducted and/or for which the target species are less generally recognized as undesirable plants may be suggested later, based on such earlier successes, but should not be attempted initially.

It will be important to maintain full forthrightness and credibility throughout each of these studies, and thereby promote the confidence of all concerned private, state, and federal agencies. Also, once biocontrol agents are released into the field, provisions must be made to monitor and evaluate their long-term activities and effectiveness. Such careful followup efforts would serve as the basis upon which the success of the program is evaluated and further conducted.

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TABLE 1. The status of biological control of weeds in Hawaii, 1981. (K=Kauai, O=Oahu, Mo=Molokai, M=Maui, H=Hawaii).

Weed Species	Site of Infestation K	O	Mo	M	H	Insect or Pathogen Species & Year of First Release	Remarks
1. *Ageratina* (=*Eupatorium*) *adenophorum* (Spreng.) K. & R. (Maui pamakani) Fam: Compositae	-	+	-	+	+	*Procecidochares utilis* Stone (Dip.: Tephritidae) 1945	Control complete at Ulupalakua, Maui, substantial at Puuwaawaa, Hawaii; partial on Oahu.
2. *Ageratina* (=*Eupatorium*) *riparia* (Regel) K. & R. (Hamakua pamakani) Fam: Compositae	-	+	-	+	+	*Oidaematophorus* sp. (Lep.: Pterophoridae) 1973	Substantial to complete control, many localities on Hawaii.
						Procecidochares alani Steyskal (Dip.: Tephritidae) 1974	Substantial to complete control, many locations on Hawaii.
						Cercosporella sp. (plant pathogen) 1975	Substantial control, many locations on Hawaii.
3. *Clidemia hirta* (L.) D. Don (Koster's curse) Fam: Melastomaceae	-	+	+	-	+	*Liothrips urichi* Karny (Thysanoptera: Thripidae) 1953	Causes some damage to plants on Oahu.
						Blepharomastix ebulealis (Guenee) (Lepidoptera: Pyralidae) 1970	Recovered on Oahu in October, 1974. Evaluation pending.
4. *Cyperus rotundus* L. (nut grass) Fam: Cyperaceae	+	+	+	+	+	*Bactra venosoma* (Zeller) (Lep.: Tortricidae) 1925	Ineffective control agent, heavy parasitism at times.
						Athesapeuta cyperi Marshall (Col.: Curculionidae) 1925	Ineffective control agent.
5. *Elephantopus mollis* H. B. K. (elephant's foot) Fam: Compositae	+	-	-	-	+	*Tetraeuaresta obscuriventris* (Loew) (Dip.: Tephritidae) 1961	Partial control on Kauai.

TABLE 1.--Continued.

Weed Species	Site of Infestation K	O	Mo	M	H	Insect or Pathogen Species & Year of First Release		Remarks
6. Emex spinosa Campd. 7. Emex australis Steinh. (emex) Fam: Polygonaceae	–	+	+	+	+	Apion antiquum Gyllenhal (Col.: Curculionidae)	1957	Control substantial on Maui, incomplete on Oahu and Molokai. On Hawaii control var ing from complete (1200 m) to partial (600 m); no control below 150 m.
						Apion violaceum var. harcyniae Hubenthal (Col.: Curculionidae)	1962	A. violaceum and A. neofallax may be established but have not been recovered. Other biocontrol candidates studied but not introduced.
						Apion neofallax Warner (Col.: Curculionidae)	1962	
8. Hypericum perforatum L. (Klamath weed) Fam: Hypericaceae	–	–	–	–	+	Zeuxidiplosis giardi (Kieffer) (Dip.: Cecidomyiidae)	1965	Substantial control on Mt. Hualalai, 2134 m elevation.
						Chrysolina quadrigemina (Suffrian) (Col.: Chrysomelidae)	1965	Partial control, low population.
						Chrysolina hyperici (Forster) (Col.: Chrysomelidae)	1965	Partial control; spread to Volcano, Hawaii where it is established on Hypericum degeneri Fosberg.
9. Lantana camara L. (lantana) Fam: Verbenaceae	+	+	+	+	+	Aerenicopsis championi Bates (Col.: Cerambycidae)	1902	Not recovered; establishment doubtful.
						Apion sp. (Col.: Curculionidae)	1902	Failed to become established.
						Blepharomastix acutangulalis (Snellen) (Lep.: Pyralidae)	1954	Failed to become established.

Catabena esula Druce (Lep.: Noctuidae)	1955	Seasonal, causes widespread defoliation in some areas Heavily parasitized by an Ichneumonid, *Echthromorpha fuscator* (Fab.).
Diastema tigris Guenee (Lep.: Noctuidae)	1954	Failed to become established.
Cremastobombycia lantanella Busck (Lep.: Gracillariidae)	1902	Present on all islands; minor importance.
Epinotia lantana (Busck) (Lep.: Tortricidae)	1902	Present on all islands; partial control.
Eutreta xanthochaeta Aldrich (Dip.: Trypetidae)	1902	Present on all islands; minor importance.
Evander xanthomelas Guerin (Col.: Cerambycidae)	1902	Failed to become established.
Hepialus sp. (Lep.: Hepialidae)	1902	Failed to become established.
Hypena strigata (F.) (Lep.: Noctuidae)	1957	Present on all islands; major Lepidopterous defoliator. Contributes partial to substantial control on Hawaii, Maui, Molokai, and Kauai.
Leptobyrsa decora Drake (Hemip.: Tingidae)	1970	Spreading slowly on Maui, Kauai and Hawaii; evaluation pending.
Octotoma gundlachi Suffrain (Col.: Chrysomelidae)	1953	Failed to propagate in quarantine insectary.
Octotoma plicatula (F.) (Col.: Chrysomelidae	1954	Not recovered.

TABLE 1.--Continued.

Weed Species	Site of Infestation K O Mo M H	Insect or Pathogen Species & Year of First Release	Remarks
		Octotoma scabripennis Guerin (Col.: Chrysomelidae) 1953	Important leafminer in some localities on Hawaii; complements other foliar insects.
		Ophiomyia lantanae Froggatt (Dep.: Agromyzidae) 1902	Not effective as a control agent.
		Plagiohammus spinipennis Thompson (Col.: Cerambycidae) 1960	Partial control in some rainfall areas of 50-130 inches. Not adapted to drier areas.
		Platyptilia pusillidactyla (Walter) (Lep.: Pterophoridae 1902	Of minor importance.
		Strymon bazochii gundlachianus (Bates) (Lep.: Lycaenidae) 1902	Of minor importance.
		Strymon echion (L.) (Lep.: Lycaenidae) 1902	Of minor importance.
		Syngamia haemorrhoidalis Guenee (Lep.: Pyralidae) 1956	Well established; contributes to stress in some localities.
		Teleonemia scrupulosa Stal (Hem.: Tingidae) 1902	Causes extensive defoliation during summer months.
		Teleonemia vanduzeei Drake (Hem.: Tingidae) 1952	Not recovered.

							Uroplata girardi Pic (Col.: Chrysomelidae)	1961	Important blotch type leaf miner which causes considerable foliar stress; well adapted to Hawaiian conditions and complements other foliar introductions.
10.	Melastoma malabathricum L. (Malabar melastome, Indian rhododendron) Fam: Melastomaceae	+	-	-	-	+	Bocchoris fatualis (Lederer) (Lep.: Pyraustidae)	1958	Leaf rolling caterpillars established on Kauai and Hawaii at low population levels.
							Bocchoris adipalis Zeller (Lep.: Pyraustidae)	1965	Leaf rolling caterpillars established on Kauai and Hawaii at low population levels.
							Selca brunella Hampson (Lep.: Nolidae)	1965	Caterpillars feed in flower buds, bore into terminal stems and cause foliar damage and dieback. Partial control. Also established on Tibouchina urvilleana in Volcano area.
11.	Myrica faya Ait. (firebush, firetree) Fam: Myricaceae	-	+	-	+	+	Strepsicrates smithiana (Walsingham) (Lep.: Olethreutidae)	1956	Failed to become established on M. faya; however, it is established on M. Cerifera L. in Panaewa Forest, Hawaii.
									Other biocontrol candidates including a pathogen were studied but failed host specificity tests or failed to propagate in quarantine insectary.
12.	Opuntia spp. (prickly pear cactus) Fam: Cactaceae	+	+	+	+	+	Dactylopius confusus (Cockerell) (Hom.: Dactylopiidae)	1949	Substantial to complete control on Hawaii by Dactylopius and Cactoblastis.
							Cactoblastis cactorum (Berg) Lep.: Pyralidae)	1950	Substantial to complete control on Hawaii together with Dactylopius. (Wind borne to all islands).

TABLE 1.--Continued.

Weed Species	Site of Infestation K O Mo M H	Insect or Pathogen Species & Year of First Release		Remarks
		Archlagocheirus funestus (Thomson) (Col.: Cerambycidae)	1951	Distribution very limited; total destruction of some plants observed. Replaced Dactylopius and Cactoblastis at 853 m in some situations.
13. Pluchea odorata (L.) Cass (hairy fleabane, sourbush) Fam: Compositae	+ + - + +	Acinia picturata (Snow) (Dip.: Tephritidae)	1958	Ineffective.
		Trichotaphe aenigmatica Clarke (Lep.: Gelechiidae)	1957	Ineffective.
14. Rubus penetrans Bailey (prickly Florida blackberry) Fam: Rosaceae	+ + - + +	Schreckensteinia festaliella (Hubner) (Lep.: Helionidae)	1963	This leaf skeletonizer is increasingly active at Volcano, Hawaii and is presently third in importance. Seasonal.
		Croesia zimmermani Clarke (Lep.: Tortricidae)	1964	Leafroller caterpillars cause foliar damage and are widespread in host range. Active throughout the year and is presently most important agent.
		Priophorus morio Lepeletier (Hym.: Tenthredinidae)	1968	This sawfly is gradually extending its range and although it causes much foliar damage, it appears to be seasonal and therefore ranked second in importance. All three established insects cause some damage at present on Hawaii.
		Bembecia marginata Harris (Lep.: Aegeridae)	1963	Failed to become established.

								Chlamisus gibbosa (F.) (Col.: Chrysomelidae)	1969	Failed to become established.
15.	*Schinus terebinthifolius* Raddi (Brazilian peppertree, Brazilian holly, Christmas berry, wilelaiki) Fam: Anacardiaceae	+	+	-	+	+		*Bruchus atronotatus* Pic (Col.: Bruchidae)	1960	Of the three listed agents for this host, only the first two are well established but are giving only partial control on Kauai, Oahu, and Hawaii. Many biocontrol candidates were studied and tested but were found nonspecific.
								Episimus utilis Zimmerman (Lep.: Tortricidae)	1954	
								Crasimorpha infuscata Hodges (Lep.: Gelechiidae)	1961	
16.	*Tribulus cistoides* L. (nohu) Fam: Zygophyllaceae	+	+	+	+	+		*Microlarinus lypriformis* Wollaston (Col.: Curculionidae)	1963	Of the two listed biocontrol agents, *M. lypriformis* has been the most effective.
17.	*Tribulus terrestris* L. (puncture vine) Fam: Zygophyllaceae	+	+	+	+	+		*Microlarinus lareynii* (Jacquelin do Val) (Col.: Curculionidae)	1952	Spread naturally to Molokai and to various infestations on each island. Control has been substantial to complete.
18.	*Ulex europaeus* L. (gorse) Fam: Leguminosae	-	-	-	+	+		*Apion ulicis* (Forster) (Col.: Curculionidae)	1952	Established on Maui and Hawaii but exerts only partial control.
								Apion scutellare Kirby (Col.: Curculionidae)	1961	Failed to become established.